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Hastreiter

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(54) **DEGRADATION MONITORING SYSTEM
FOR HOSE ASSEMBLY**

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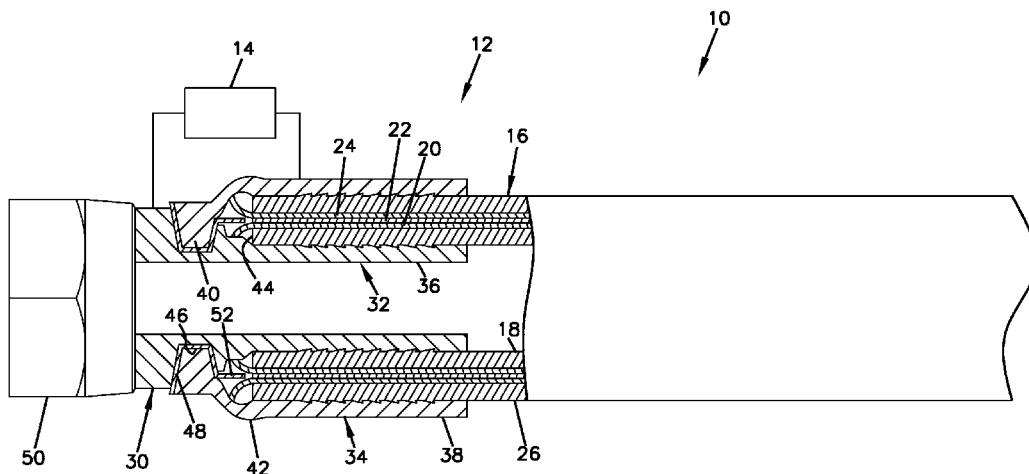
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(57) **ABSTRACT**

A system and method for detecting hose degradation are disclosed. In one aspect, a hose degradation monitoring system includes a hose assembly including a hose having a first conductive layer and a second conductive layer, and a monitoring circuit in electrical communication with the first and second conductive layers. The degradation monitoring circuit includes a circuit element having a non-linear electrical property in response to changed voltage.

14 Claims, 11 Drawing Sheets



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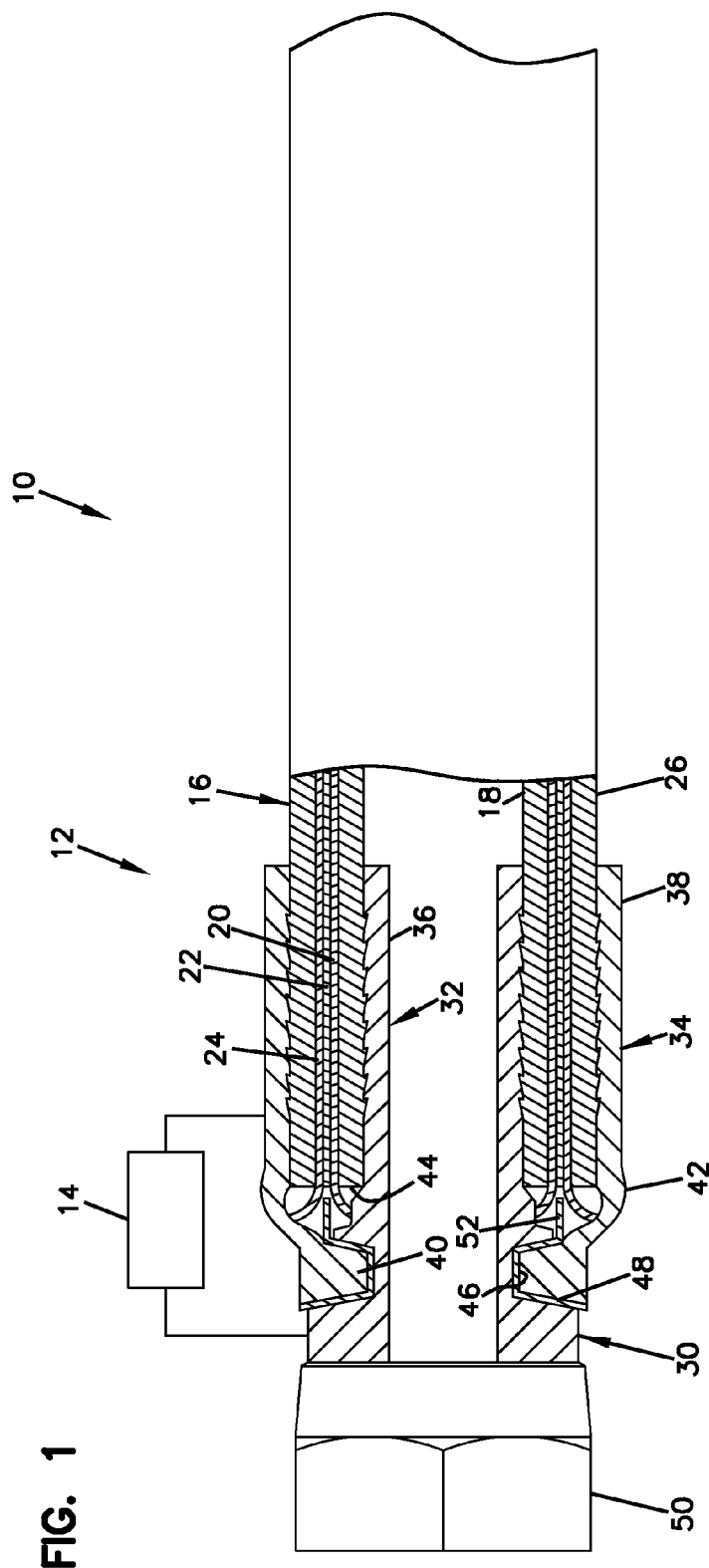


FIG. 2

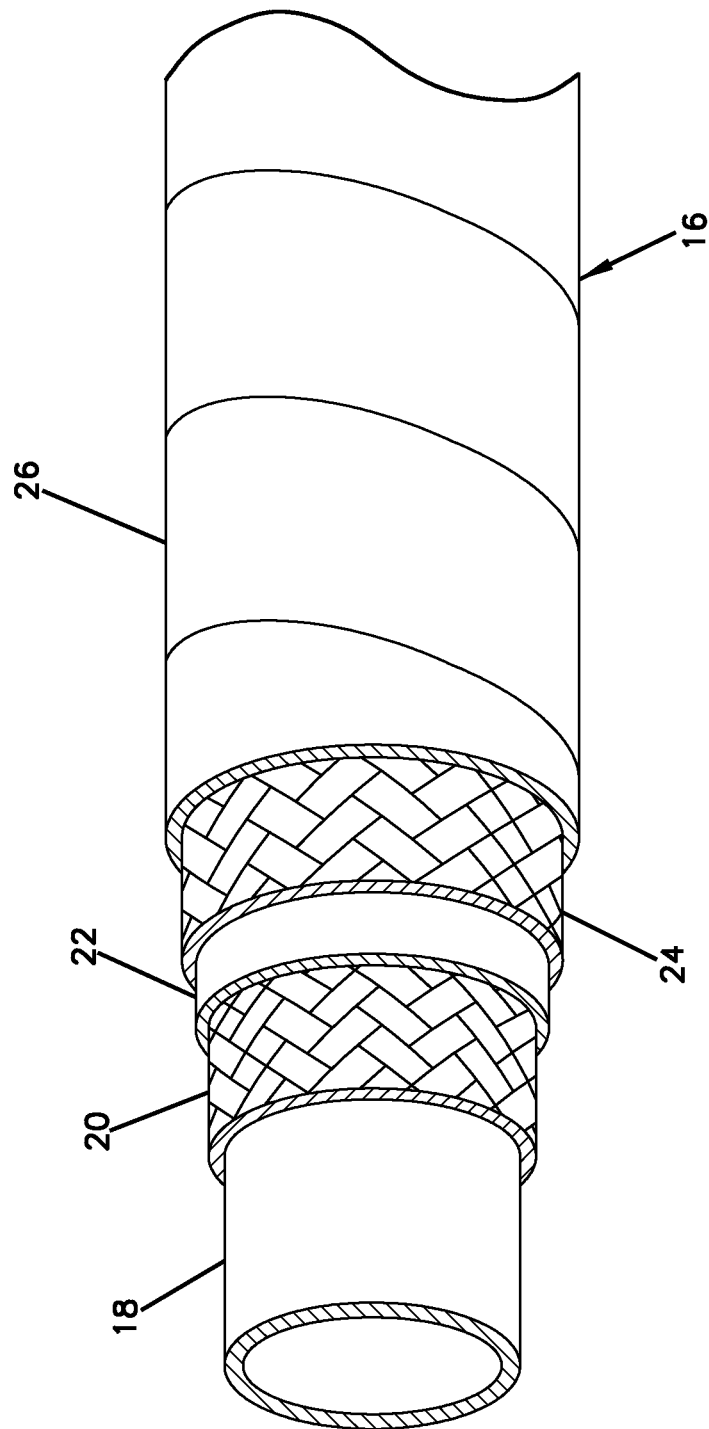
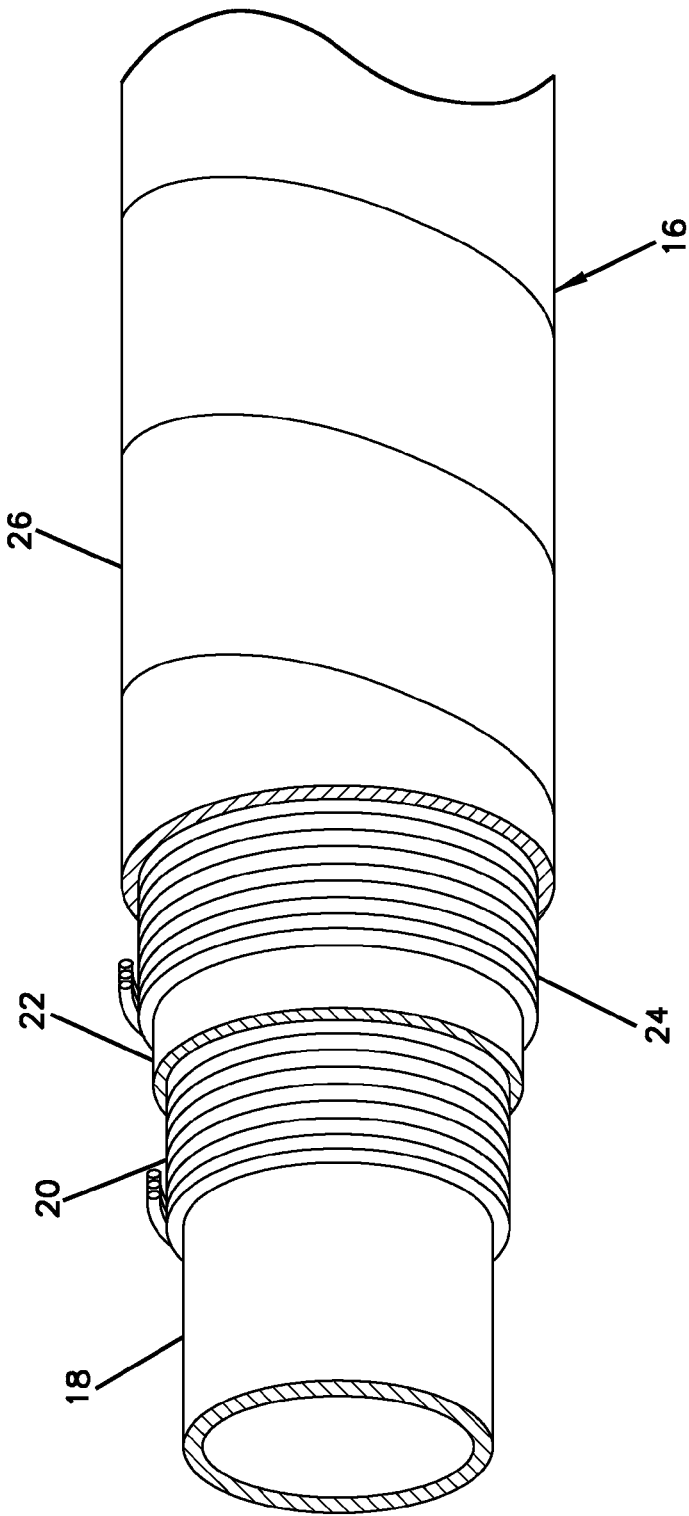
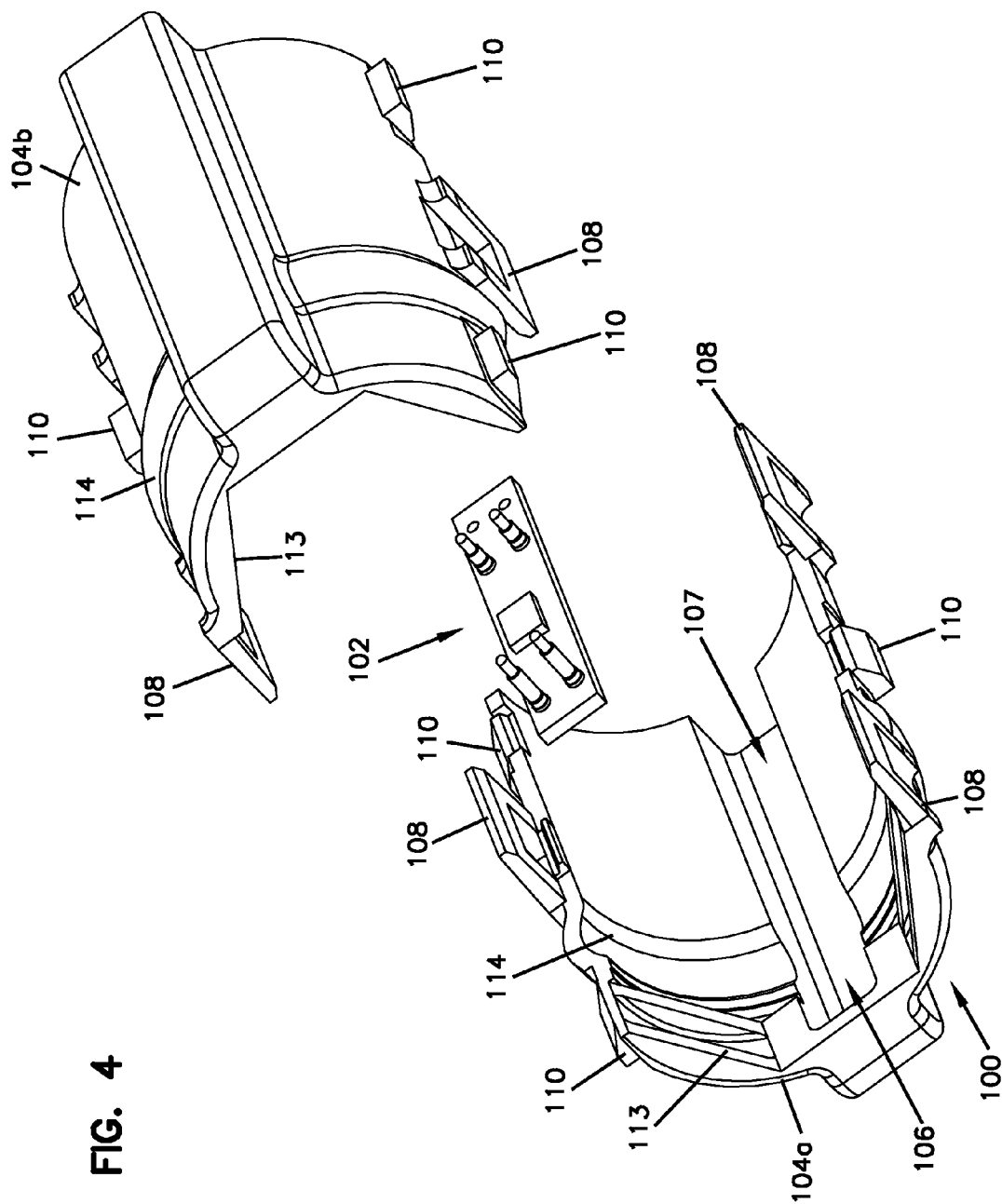


FIG. 3





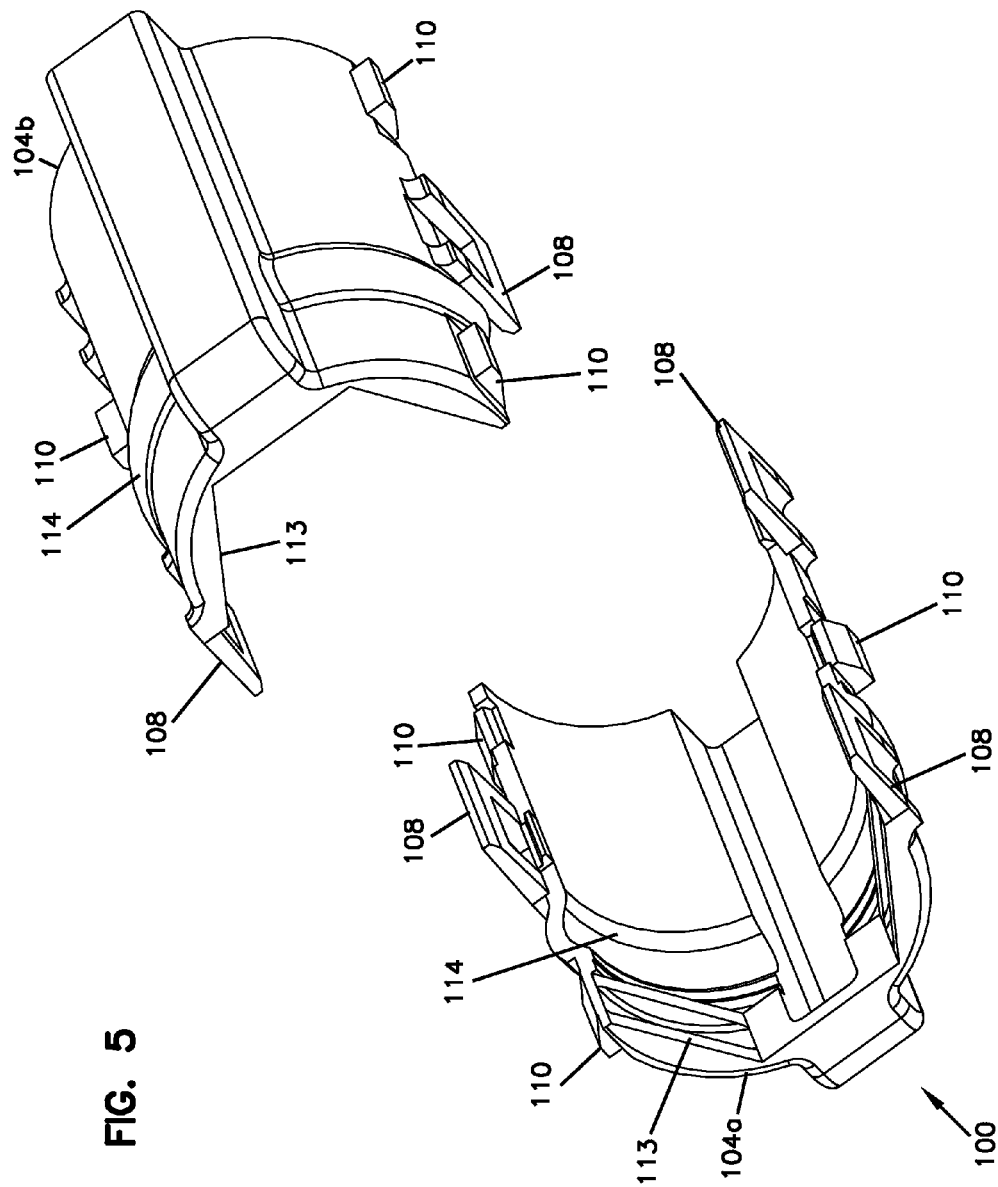


FIG. 6

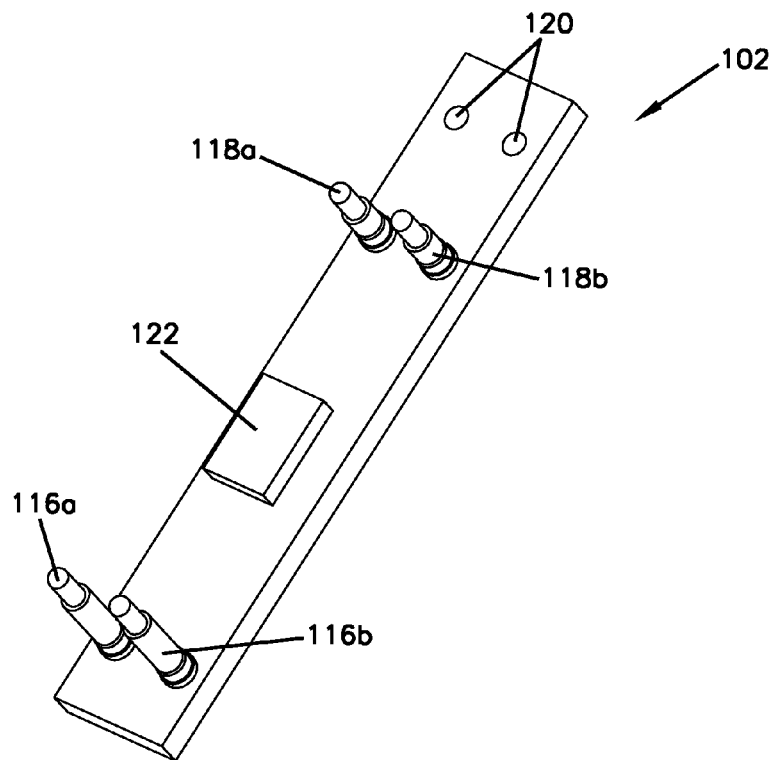


FIG. 7

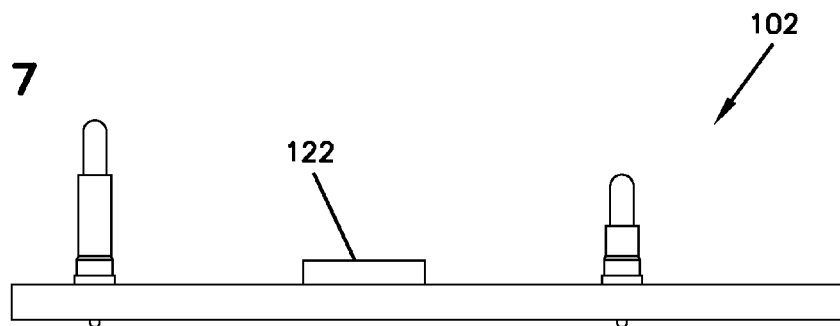


FIG. 8

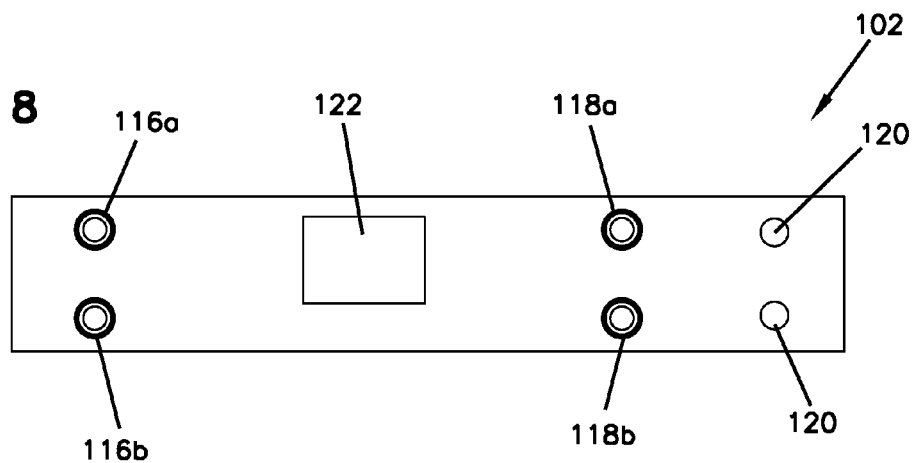
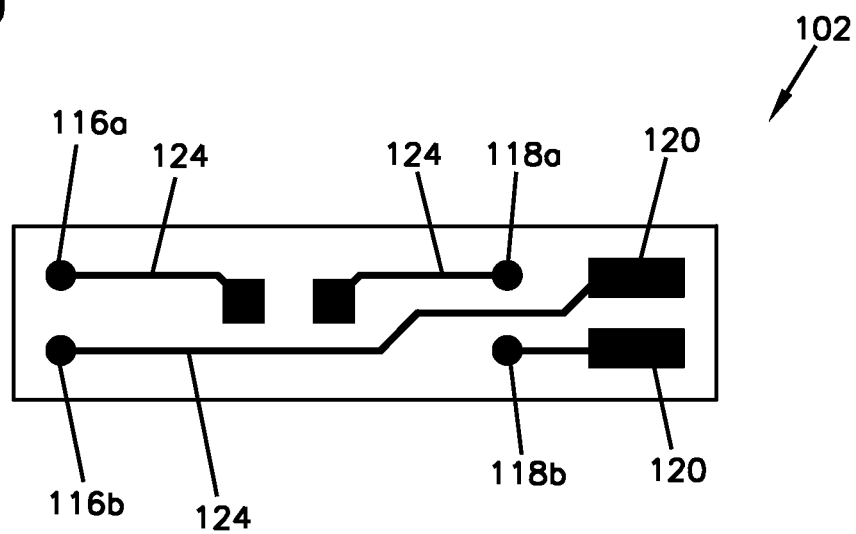


FIG. 9



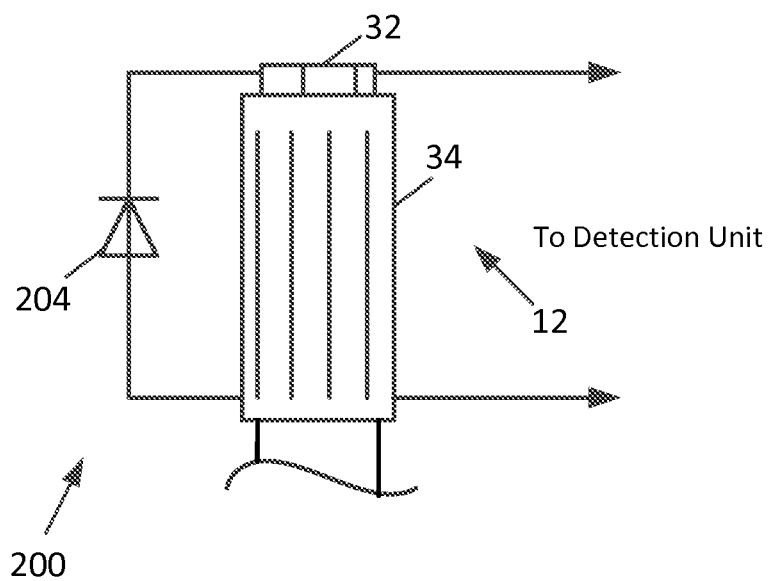


FIG. 10

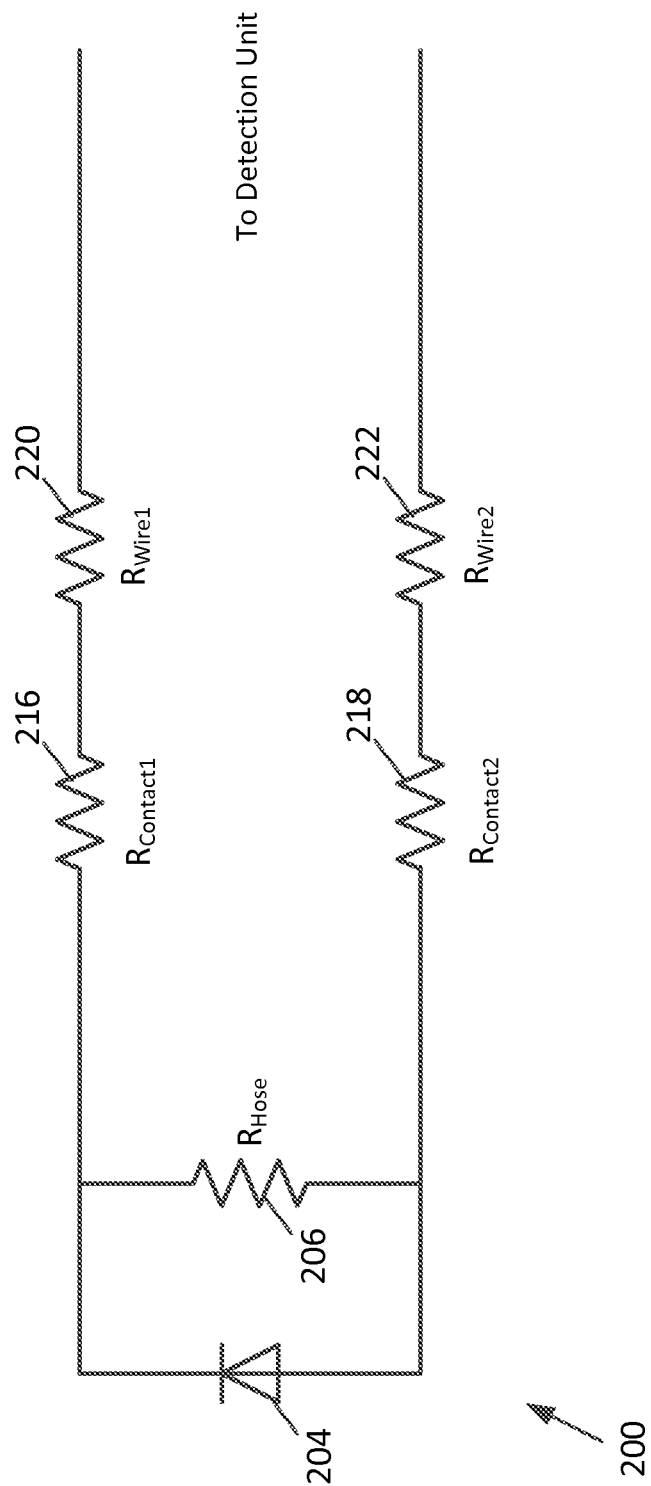


FIG. 11

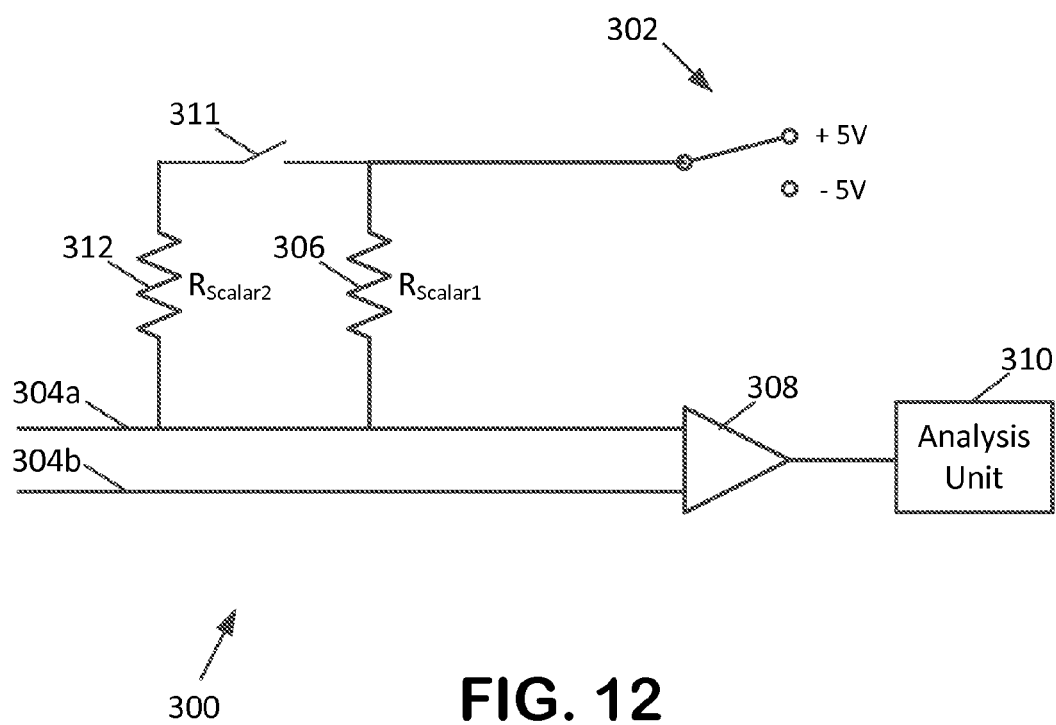
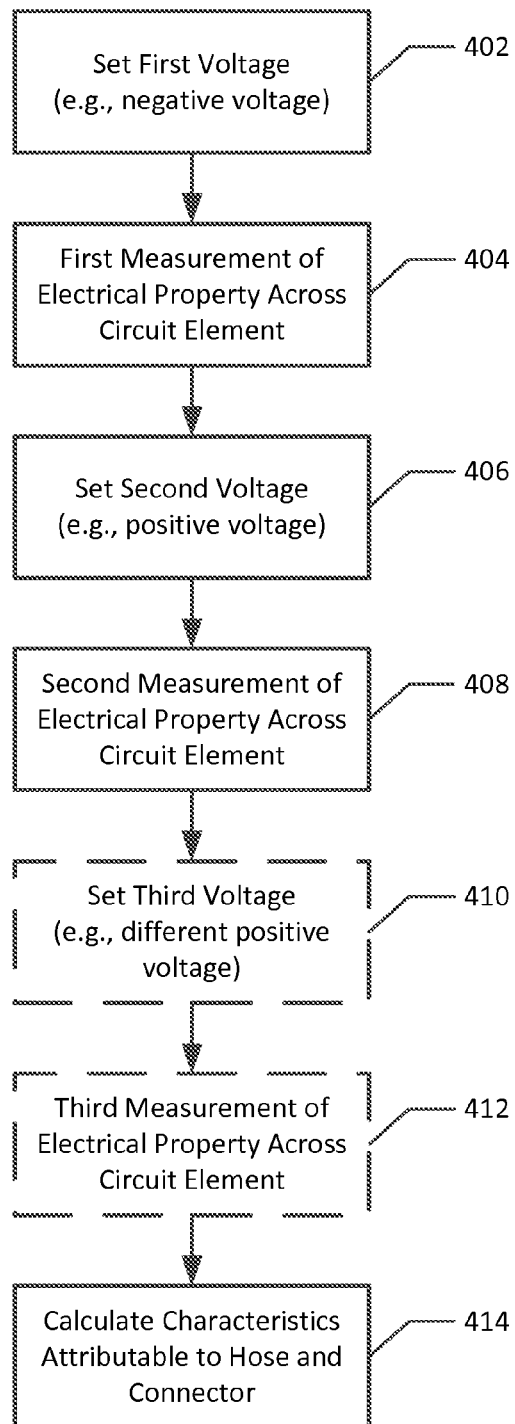


FIG. 12



400

FIG. 13

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DEGRADATION MONITORING SYSTEM FOR HOSE ASSEMBLY

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority to U.S. Provisional Patent Application No. 61/480,924, filed Apr. 29, 2011, the disclosure of which is hereby incorporated by reference in its entirety.

BACKGROUND

High pressure reinforced hydraulic hose is typically used on a variety of fluid power operated machines, such as earth-moving machines, to provide a flexible connection between several moving parts of a hydraulic circuit employed on or within the machine. Such hoses may include a hollow polymeric inner tube on which successive cylindrical layers of reinforcing material, such as wire or textile, are concentrically applied to contain the radial and axial pressures developed within the inner tube.

Many applications are demanding hose constructions with both high burst strength and long term fatigue resistance. Using conventional technology, the burst strength of a hose design may be increased by adding additional reinforcing material and/or layers, a practice which is generally discouraged because of its negative impact on the flexibility of the hose, or by universally increasing the tensile strength of each layer of reinforcement material, which may come at the expense of hose fatigue resistance.

To determine the robustness of a hose design, a hose manufacturer typically performs, among other tests, an impulse test and a burst test on the hose. An impulse test measures a hose design's resistance to fatigue failure by cyclically subjecting the hose to hydraulic pressure. A burst test, on the other hand, is a destructive hydraulic test employed to determine the ultimate strength of a hose by uniformly increasing internal pressure until failure. Based on these and other tests, a manufacturer can estimate a hose life that can be used to determine when a hose has reached the end of its life and may require replacing.

In some circumstances, it is desirable to detect, in a non-destructive and non-disruptive manner a likelihood of failure of a hydraulic hose. One solution providing this capability is discussed in U.S. Pat. No. 7,555,936, and discloses connecting a monitor circuit between two parallel, at least partially-conductive layers of a hose wall. A change in an electrical property observed by that monitor circuit may indicate a change in a property of the hose wall structure that might indicate impending failure of the hose wall. However, even with this solution, it can be difficult to determine whether the changed electrical property is in fact due to a change in a physical feature of a hose wall, or if the changed electrical property is due to a change in the sensing electronics, a change in an electrical property of a harness connecting the monitoring circuit to the hose wall, or simply degradation of an electrical connection to the hose wall. In these cases, there may be a change in an electrical property observed, even when hose wall integrity is not compromised.

SUMMARY

An aspect of the present disclosure relates to a hose degradation monitoring system. The system includes a hose assembly including a hose having a first conductive layer

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and a second conductive layer, and a monitoring circuit in electrical communication with the first and second conductive layers. The degradation monitoring circuit includes a circuit element having a non-linear electrical property in response to changed voltage.

A second aspect of the present disclosure relates to a method of monitoring degradation of a hose assembly. The method includes applying a first voltage across a circuit element connected between first and second conductive layers of a hose assembly, and concurrently detecting a first electrical characteristic of the circuit element. The method further includes applying a second voltage across the circuit element, the second voltage different from the first voltage, and concurrently detecting a second electrical characteristic of the circuit element. The method also includes calculating an electrical characteristic of the hose assembly based at least in part on the first and second electrical characteristics.

A third aspect of the present disclosure relates to a hose degradation monitoring system that includes a hose assembly, a monitoring circuit, and a monitoring assembly. The hose assembly includes a first conductive layer and a second conductive layer, and the monitoring circuit includes a diode electrically connected between the first conductive layer and the second conductive layer. The diode has a resistance that changes non-linearly as a function of voltage applied across the diode. The monitoring assembly includes a housing and a circuit board, with the circuit board positioned in a channel of the housing and including electrical contacts oriented toward the hose assembly. The electrical contacts electrically connect the monitoring circuit to the first and second conductive layers.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a partial cross-sectional view of an exemplary hose assembly employing a fault detector having exemplary features of aspects in accordance with the principles of the present disclosure.

FIG. 2 is a perspective view, partially cut away, illustrating an exemplary hose employing a braided conductive layer that is suitable for use with the hose assembly of FIG. 1.

FIG. 3 is a perspective view, partially cut away, illustrating an exemplary hose employing a spiral wire conducting layer that is suitable for use with the hose assembly of FIG. 1.

FIG. 4 is an exploded perspective view of a monitoring assembly installable on a portion of a hose illustrated in FIG. 1.

FIG. 5 is an exploded perspective view of a housing forming a portion of the monitoring assembly of FIG. 4.

FIG. 6 is a perspective view of a circuit board encased by the housing of FIG. 5.

FIG. 7 is a side plan view of the circuit board of FIG. 6.

FIG. 8 is a top plan view of the circuit board of FIG. 6.

FIG. 9 is a schematic trace view of the circuit board of FIG. 6.

FIG. 10 is a generalized schematic view of a monitoring circuit included in the monitoring assembly of FIGS. 4-10, as integrated with the hose assembly of FIGS. 1-3.

FIG. 11 is a logical circuit representation of components of an integrated monitoring assembly and hose assembly of FIG. 10.

FIG. 12 is a schematic view of a diagnostic unit useable in conjunction with the monitoring assembly of FIGS. 4-9.

FIG. 13 is a representation of a method for monitoring the structural integrity of the hose assembly of FIG. 1.

DETAILED DESCRIPTION

Reference will now be made in detail to the exemplary aspects of the present disclosure that are illustrated in the accompanying drawings. Wherever possible, the same reference numbers will be used throughout the drawings to refer to the same or like structure.

Referring now to FIG. 1, an exemplary hose fault detection system, generally designated 10, is shown. The hose fault detection system 10 includes a hose assembly, generally designated 12, and a monitoring assembly 14 in electrical and physical communication with the hose assembly 12.

The hose assembly 12 includes a hose, generally designated 16, having a multi-layer construction. In the subject embodiment, the hose 16 is generally flexible and includes an inner tube 18 made from a polymeric material, such as rubber or plastic, or another material depending on the requirements of the particular application, a first conductive layer 20, an intermediate layer 22, a second conductive layer 24 and an outer cover 26. The first and second conductive layers 20, 24 define an electrical characteristic of the hose assembly 12, such as resistance.

In the subject embodiment, the first conductive layer 20 overlays the inner tube 18 and the intermediate layer 22 overlays the first conductive layer 20. The second conductive layer 24 overlays the intermediate layer 22. The first and second conductive layers 20, 24 may be configured as reinforcing layers. The outer cover 26 may overlay the second conductive layer 24, and may include, for example, an extruded layer of rubber or plastic. The outer cover 26 may itself include a reinforcing layer.

The intermediate layer 22 operates to at least partially insulate electrically the first and second conductive layers 20, 24 from one another. The intermediate layer 22 may have any of a variety of constructions. For example, the intermediate layer 22 may consist of a single layer of an electrically resistive material. The intermediate layer 22 may also consist of multiple layers, wherein at least one of the layers exhibits electrical insulating properties. Certain composite materials may also be employed in the intermediate layer 22, such as a woven fabric bonded to a polymeric material. Composite materials having various other constructions may also be utilized. Composite materials may also be used in combination with other materials to form the intermediate layer 22.

The first and second conductive layers 20, 24 generally extend the entire length and span the entire circumference of the hose. This is generally the case when the conductive layer also functions as a reinforcement layer. The intermediate layer 22 may also extend over the entire length and circumference of the hose. There may be instances, however, where at least one of the first and second conductive layers 20, 24 extends only over a portion of the hose length and/or a portion of its circumference. In that instance, the intermediate layer 22 may also be configured to generally extend over the region of the hose containing the partial conductive layer 20, 24. The partial intermediate layer 22 may be positioned within the hose so as to separate the first and second conductive layers 20, 24 from one another.

Referring now to FIGS. 2 and 3, the first and second conductive layers 20, 24 may include, for example, an electrically conductive braided reinforcement material, such as shown in FIG. 2, or alternating layers of electrically

conductive spiral reinforcement material, such as shown in FIG. 3. The braided reinforcement material may consist of a single layer or may include multiple layers. Although a two-wire spiral reinforcement arrangement is depicted in FIG. 3, it shall also be appreciated that other configurations, such as four and six wire arrangements, may also be utilized.

The first and second conductive layers 20, 24 may each have the same configuration, or each layer may be configured differently. For example, the first and second conductive layers 20, 24 may each include the braided material shown in FIG. 2, or one of the first and second conductive layers 20, 24 may include the braided material while the other of the first and second conductive layers 20, 24 may include the spiral reinforcement material shown in FIG. 3. Additionally, the first and second conductive layers 20, 24 may include a single ply or multiple plies of reinforcement material. The first and second conductive layers 20, 24 may comprise metal wire, natural or synthetic fibers and textiles, and other reinforcement materials, provided the selected material is electrically conductive.

Referring again to FIG. 1, the hose assembly 12 may include a hose fitting, generally designated 30, for fluidly coupling the hose 16 to another component. The hose fitting 30 may have any of a variety of different configurations depending, at least in part, on the requirements of the particular application.

In the subject embodiment, the hose fitting 30 includes a nipple, generally designated 32, that engages the inside of the hose 16 and a socket, generally designated 34, that engages the outside of the hose 16. The nipple 32 includes an elongated cylindrical end portion 36 that engages the inner tube 18 of the hose 16. A cylindrically shaped end portion 38 of the socket 34 engages the outer cover of the hose 16. The socket 34 and nipple 32 may be constructed from an electrically conductive material.

The socket 34 and nipple 32 can be secured to the hose 16 by crimping the end portion 38 of the socket 34 overlaying the hose 16. The crimping process deforms the end portion 38 of the socket 34, thereby compressing the hose 16 between the nipple 32 and the socket 34. In the subject embodiment, the portions of the nipple 32 and the socket 34 that engage the hose 16 include a series of serrations that at least partially embed into the relatively softer hose material when the socket 34 is crimped to help secure the hose fitting 30 to the hose 16. The serrations may be configured to prevent the serrations from penetrating the inner tube and outer cover and contacting the first and second conductive layers 20, 24.

In the subject embodiment, the socket 34 includes an inwardly extending circumferential lug 40 positioned near an end 42 of the socket 34 adjacent an end 44 of the hose 16. The lug 40 engages a corresponding circumferential slot 46 formed in the nipple 32 for securing the socket 34 to the nipple 32. The end 42 of the socket 34 having the lug 40 is initially formed larger than the nipple 32 to enable the socket 34 to be assembled onto the nipple 32. During the assembly process the end 42 of the socket 34 is crimped, which deforms the socket 34 and forces the lug 40 into engagement with the corresponding slot 46 in the nipple 32. The socket 34 can be electrically insulated from the nipple 32 by positioning an electrically insulating collar 48 between the socket 34 and nipple 32 at the point the lug 40 engages the slot 46.

The hose fitting 30 also includes a nut 50 rotatably attached to the nipple 32. The nut 50 provides a means for securing the hose assembly 12 to another component.

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The first conductive layer **20** may be configured to extend beyond the end of the inner tube of the hose **16**. The first conductive layer **20** may engage the nipple **32** to create an electrical connection between the nipple **32** and the first conductive layer **20**. Similarly, the second conductive layer **24** may be configured to extend beyond an end of the outer cover of the hose **16**. The second conductive layer **24** may engage the socket **34** to create an electrical connection between the socket **34** and the second conductive layer **24**.

To help prevent the portions of the first and second conductive layers **20**, **24** that extend beyond the end of the hose **16** from contacting one another, an electrically insulating spacer **52** may be positioned between the exposed ends of the first and second conductive layers **20**, **24**. The spacer **52** may be integrally formed as part of the collar **48** used to electrically insulate the socket **34** from the nipple **32**. The spacer **52** may also be formed by extending the intermediate layer **22** of the hose **16** beyond an end of the inner tube **18** and outer cover **26**. The spacer **52** may also be configured as a stand alone component separate from the collar **48** and the intermediate layer **22** of the hose **16**.

The monitoring assembly **14** may have any of a variety of configurations. In general, the monitoring assembly **14** is connectable over a portion of the hose assembly **12**, in particular the portion illustrated in FIG. 1. The monitoring assembly **14**, when installed over hose assembly **12**, forms a physical and electrical connection with the hose assembly **12**, and in particular to nipple **32** and socket **34**, respectively. Generally, the monitoring assembly **14** detects an electrical characteristic of the hose assembly **12**, while validating the connection to the nipple **32** and socket **34**. An exemplary monitoring assembly **14** is described in further detail below, in connection with FIGS. 4-11.

Referring now to FIGS. 4-9, additional structural details of an example monitoring assembly **14** installable on a portion of the hose assembly **12** are shown. The monitoring assembly includes housing **100** and a circuit board **102**.

In the embodiment shown, the housing **100** includes first and second shell pieces **104a-b** which are shaped to be joined together to form the generally hollow cylindrical housing **100**, which is sized and positioned to enclose an end portion of the hose assembly **12**. The housing **100** includes a channel **106** within at least one of the shell pieces **104a-b** within which the circuit board can be seated and positioned to engage the hose assembly **12**. In some embodiments, the channel **106** has an open end **107**, allowing wire leads to enter the housing **100** and connect to the circuit board **102**.

The shell pieces **104a-b** include complementary snap-fit connectors **108**, **110** positioned on opposed mating edges **112** of the shell pieces, such that the shell pieces **104a-b** can be disengageably interconnected. In alternative embodiments, the housing **100** can be constructed from one or more shell pieces, and can be constructed to be either disengageable or sealed around the hose assembly **12**. In some embodiments, the shell pieces can be formed from plastic, and are weather resistant to protect the circuit board **100**.

When the shell pieces **104a-b** are joined, the housing **100** forms a generally hexagonal inner surface **113** along one end that is complementary to the nut **50**. Additionally, a band **114** is formed circumferentially along the housing **100** over the end **42** of the socket **34**. The band **114** prevents the housing from sliding off the hose assembly **12** in the direction of the nut **50**, or down along the length of the hose **16**. Additionally, because in this embodiment the nut **50** has a diameter generally smaller than the hose **16**, the housing **100** will not slide down the length of the hose **16**.

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Referring now specifically to FIGS. 6-9, the circuit board **102** includes two pairs of contacts **116a-b**, **118a-b**, and a circuit element **122**. In the embodiment shown, the circuit element **122** is a diode, additional details of which are discussed below in connection with FIGS. 10-13. The circuit board **102** is positioned within the channel **106** of the housing **100**, such that a front face (i.e., a side of the circuit board including the contacts **116a-b**, **118a-b** and circuit element **122**) of the circuit board is oriented toward the hose assembly **12**.

In the embodiment shown, when positioned within the channel **106** the first pair of contacts **116a-b** are each positioned to electrically connect to nipple **32**, and the second pair of contacts **118a-b** are positioned to electrically connect to socket **34**. Wire connection pads **120** are connected to the first and second pair of contacts **116a-b**, **118a-b**, respectively, as well as a circuit element **122**, via circuit board tracks **124**, to form the circuit illustrated in FIGS. 10-11, below. Wire connection pads **120** can receive soldered or otherwise electrically bonded connections to wires leading to a diagnostic unit, an example of which is illustrated in FIG. 12.

FIG. 10 illustrates a general schematic view of a circuit **200** formed with the hose assembly **12** to monitor its degradation. The circuit **200** includes a monitoring circuit **202**, which can be, in some embodiments, positioned on the circuit board **102** of FIGS. 4 and 6-9. The monitoring circuit **202** includes a circuit element, illustrated as diode **204**, connected between the socket **34** and the nipple **32**, thereby connecting the diode between the first and second conductive layers **20**, **24** of the hose **16**. Although in this embodiment a diode is shown, it is recognized that any circuit element could be used, if it has a non-linear electrical property which includes a non or low conducting state in response to changed voltage.

In use, the monitoring circuit **202** can be used to detect an electrical property of the hose, for example a resistance of the hose. Although this could otherwise be tested by applying a voltage directly across the nipple **32** and socket **34**, that arrangement would be subject to false readings, because it would obtain a false failure signal in case of a failed connection between the voltage source and the hose assembly **12** occurring at the electrical contacts **116a-b**, **118a-b**. Accordingly, use of two or more readings at different voltage levels for conducting and non-conducting states of a circuit element **204** allows for verification that open-circuit conditions are not the cause of a particular reading.

In general, it is noted that although the circuit **202** is intended to monitor an electrical property of the first and second conductive layers **20**, **24**, additional features of the hose assembly **12** and monitoring assembly **14** contribute to overall measurements made by a diagnostic unit. FIG. 11 illustrates a schematic representation of the overall circuit **200**, including the various resistive effects introduced by the hose assembly **12** and monitoring assembly **14**. In this illustration, the diode **204** is connected in parallel across the hose assembly **12**, which is represented by a hose resistance **206** (R_{Hose}).

Additional resistances within the circuit **200** exist as well, and are accounted for in the schematic view depicted in FIG. 11. These include resistance caused when the contacts **116a-b**, **118a-b** are electrically connected to the socket **34** and nipple **32**. These resistances are represented by contact resistances **216**, **218** ($R_{Contact1}$, $R_{Contact2}$, respectively). Additionally, resistance for the wires leading to a diagnostic

unit are depicted as resistances **220**, **222** (R_{wire1} , R_{wire2}), since monitoring of the circuit response will typically occur at the diagnostic unit.

In general, contact and wire resistances in hose assembly and monitoring assembly are assumed to be constant during the time and for the conditions in which hose resistance is calculated. If the voltage/current characteristics of the circuit element (e.g., diode) are known, then the remaining unknown circuit values are the hose resistance **206** (R_{Hose}), and a total resistance in the circuit **200**. To obtain those two values, two measurements can be performed to obtain readings from which the unknown values can be derived. In some embodiments, a first measurement occurs when the diode **204** is in a conducting (e.g., forward-biased) state, and a second measurement occurs when the diode **204** is in a non-conducting (e.g., reverse-biased) state.

Although in the embodiments discussed herein the diode is positioned at a connectorized end of a hose assembly, it is recognized that the diode and/or contacts could be located elsewhere along the hose, such as at an opposite end of the hose assembly. Additionally, although in the embodiment discussed herein it is noted that hose resistances are considered, a capacitive effect of the hose could be considered as well, alongside a nominal contamination resistance present due to noise from the contact assembly.

Referring now to FIG. **12**, a schematic view of a diagnostic unit **300** is shown. The diagnostic unit **300** can be used, for example to apply a stimulus to the circuit **200** of FIGS. **10-11**, and to derive an electrical characteristic for the hose assembly **12**. By taking repeated measurements of such an electrical characteristic, changes over time can indicate degradation of the hose **16** within the hose assembly **12**.

In the embodiment shown, the diagnostic unit includes a switching voltage source **302** connected to a first wire **304a** of a pair of wires **304a-b** via a resistor **306** ($R_{Scalar1}$). In the embodiment shown, the switching voltage source **302** is capable of providing a +5V or -5V signal onto wires **304a-b**, by selectively applying a 5V source to one or the other of wires **304a-b**. However, in other embodiments, the switching voltage source **302** can include additional switches and/or voltage levels or voltage dividers. In the example shown, an additional resistor **312** ($R_{Scalar2}$) is selectively incorporated into the circuit of the diagnostic unit **300** using a voltage divider switch **311** to provide positive and negative voltages of multiple levels onto wires **304a-b**.

The pair of wires **304a-b** lead from the diagnostic unit **300** to the circuit **200**, and can for example represent an opposite end of the wires extending to the diagnostic unit illustrated in FIGS. **10-11**. In some embodiments, the pair of wires **304a-b** lead from a location of the hose assembly **12** to a control panel, such as a panel within a cab of a vehicle on which the hose assembly **12** is installed. Other routing arrangements for the pair of wires **304a-b** are possible as well.

The diagnostic unit **300** also includes a voltage sensor **308** connected to an analysis unit **310**. The voltage sensor **308** is connected across the pair of wires **304a-b**, and an output indicating a current level within the circuit is passed to the analysis unit **310** to perform one or more calculations to determine an electrical characteristic for the hose assembly **12**. The analysis unit **310** can take any of a number of forms. In some embodiments, the analysis unit **310** is a programmable circuit configured to execute program instructions. Embodiments of the analysis unit **310** can be practiced in various types of electrical circuits comprising discrete electronic elements, packaged or integrated electronic chips containing logic gates, a circuit utilizing a microprocessor,

or on a single chip containing electronic elements or microprocessors. In addition, aspects of the analysis unit **310**, such as the calculations discussed herein, can be practiced within a general purpose computer or in any other circuits or systems.

In the embodiment shown, and using the switching voltage source **302**, and/or switched scalar resistors **306**, **312** (using voltage divider switch **311**), voltage sensor **308**, and analysis unit **310**, two or more measurements can be taken in a circuit such as circuit **200** of FIGS. **10-11**. These measurements can be taken using voltages having opposite polarities (e.g., using the switching voltage source **302**) or having different voltages of the same polarity (e.g., using voltage divider switch **311** with resistors **306**, **312**). For example, a first measurement can be a measurement of voltage (e.g., the output of voltage sensor **308**) with a first voltage having a magnitude and polarity for forward biasing the diode. The second measurement can be a measurement of current at the voltage sensor **308** with a voltage magnitude and polarity for reverse-biasing the diode. Typically, the second measurement can simply be a measurement using a voltage of negative polarity to that used for the first measurement, e.g., using the switching voltage source. Alternatively, if the diode is replaced with another device or circuit having a non-conducting state with a forward voltage level, then a voltage of positive polarity can be used for the second measurement. These measurements can be used to derive an electrical characteristic, for example resistance, of a circuit **200**, from which a hose resistance **206** (R_{Hose}) and contact resistance **210** ($R_{Contact}$) can be derived.

In some embodiments in which more accurate resistances are required, a third measurement can also be taken, which will allow the characteristics of the diode to be better calculated. For example, the third measurement can be a measurement at a polarity for forward-biasing the diode, but at a scalar resistance or voltage different from the voltage used for the first measurement (e.g., using a voltage divider circuit including switched scalar resistor **312** and voltage divider switch **311**). Additional details regarding the particular calculations capable of being performed using the analysis unit are discussed below in connection with FIG. **13**.

FIG. **13** is a representation of a method **400** for monitoring the structural integrity of the hose assembly of FIG. **1**. The method **400** illustrates an example method for measuring an electrical characteristic of a hose assembly **12** using a circuit element having a non-linear response to voltage and/or current. In some embodiments, and in the illustrated example measurements discussed herein, the method **400** can be used in a circuit having a diode (e.g., diode **204**) connected across the nipple **32** and socket **34**, thereby connecting the diode between the first and second conductive layers **20**, **24**.

According to the embodiment shown, a first electrical signal (e.g., voltage or current) can be applied across the circuit element (step **402**). In some embodiments, the first electrical signal can be generated from a switching voltage source **302**, and can be configured such that the diode is reverse-biased, e.g., an application of approximately -5 V. A first electrical property of the hose assembly and monitoring assembly (e.g., the collective circuit illustrated in FIGS. **10-11**) can be determined (step **404**) while the first electrical signal is applied. The first electrical property can be, for example, based on an observed voltage, using voltage sensor **308** of FIG. **12**. In the example of circuit **200**, above, when the diode is reverse-biased, the observed voltage will allow observation of an electrical characteristic total resistance

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based on the contact and wire resistances, as well as the hose resistance **206** (R_{Hose}). This is because the diode will approximate an open circuit if connections are made properly to the hose assembly **12**. This first total resistance (R_{T1}) can be represented by the following equation:

$$R_{T1} = R_C + R_H$$

A second measurement can be performed by applying a second electrical signal across the circuit element (step **406**) such that the diode is forward-biased. In this arrangement, the electrical property of the hose assembly and monitoring assembly can again be determined while this second electrical signal is applied (step **408**). In the example circuit **200** including the diode **204**, because that diode has a non-linear relationship with respect to applied voltage, current will pass through the diode and the diode will approximate a closed circuit having some resistance component (R_{D2}) given the diode characteristic of diode forward voltage (V_{D2}) at diode current (I_{D2}). The resistance of the diode in this arrangement can be represented by the following equation, where I_{T2} is the total current:

$$R_{D2} = \frac{V_{D2}}{I_{D2}} = \frac{V_{D2}}{I_{T2} - \frac{V_{D2}}{R_H}}$$

The current through the diode **204** can be calculated using a current divider equation, with a portion of current passing through the diode and a portion passing through the hose resistance (R_{Hose}). This current is represented by the equation:

$$I_{D2} = I_{T2} - \frac{V_{D2}}{R_H}$$

Accordingly, resistance component (R_{D2}) can be expressed as:

$$R_{D2} = \frac{V_{D2}}{I_{D2}} = \frac{V_{D2}}{I_{T2} - \frac{V_{D2}}{R_H}}$$

A second total resistance (R_{T2}) of the circuit will be a combination of the contact resistance with the parallel hose and diode resistances, represented as follows:

$$R_{T2} = R_C + \frac{R_H \times R_{D2}}{R_H + R_{D2}}$$

Because the total current (I_{T1} and I_{T2}) through the circuit **200** can be calculated by the analysis unit **310** as (voltage **302** minus voltage sensor **308**) divided by scalar resistance **306** and/or **312**, the first and second total resistance (R_{T1} and R_{T2}) can be calculated as voltage sensor **308** divided by total current (I_{T1} and I_{T2}).

Following determination of the electrical characteristics of the overall circuit, the analysis unit **310** can calculate an electrical characteristic attributable to the hose assembly **12** (step **414**). In the example above in which two measurements are made, a hose resistance can be determined by subtracting the second total resistance (R_{T2}) (in which the

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diode acted as a resistor in parallel with the hose resistance) from the first total resistance (in which the diode acted as an open circuit), according to the following equation:

$$R_{T1} - R_{T2} = R_H - \frac{R_H \times R_{D2}}{R_H + R_{D2}} = R_H - \frac{R_H \times \frac{V_{D2}}{I_{T2} - \frac{V_{D2}}{R_H}}}{R_H + \frac{V_{D2}}{I_{T2} - \frac{V_{D2}}{R_H}}}$$

Solving for the hose resistance **206** (R_{Hose}) results in the following equation:

$$R_H = R_{T1} - R_{T2} + \frac{V_{D2}}{I_{T2}}$$

The assumed diode voltage can be used in the above equation, or to achieve more accurate calculation of an electrical characteristic of the hose assembly, an additional measurement can be taken to calculate the forward diode forward bias voltage (V_{D2}). In some embodiments, a third measurement can be performed by applying a third electrical signal across the circuit element (step **410**) such that the diode is forward-biased, but at a different voltage from the second measurement of step **406**. This can be accomplished, for example, by switching in a lower or higher voltage source, or by including a switch-activated scalar resistor. In this arrangement, the electrical property of the hose assembly and monitoring assembly can again be determined while this third electrical signal is applied (step **412**). Total resistance (R_{T3}) is derived the same as total resistance (R_{T2}).

$$R_{T2} - R_{T3} = \frac{R_H \times R_{D2}}{R_H + R_{D2}} - \frac{R_H \times R_{D3}}{R_H + R_{D3}}$$

$$R_{T2} - R_{T3} = \frac{R_H \times \frac{V_{D2}}{I_{T2} - \frac{V_{D2}}{R_H}}}{R_H + \frac{V_{D2}}{I_{T2} - \frac{V_{D2}}{R_H}}} - \frac{R_H \times \frac{V_{D3}}{I_{T2} - \frac{V_{D3}}{R_H}}}{R_H + \frac{V_{D2}}{I_{T3} - \frac{V_{D3}}{R_H}}}$$

$$R_{T2} - R_{T3} = \frac{R_H \times V_{D2}}{R_H \times I_{T2} - V_{D2} + V_{D2}} - \frac{R_H \times V_{D3}}{R_H \times I_{T3} - V_{D3} + V_{D3}}$$

$$R_{T2} - R_{T3} = \frac{R_H \times V_{D2}}{R_H \times I_{T2}} - \frac{R_H \times V_{D3}}{R_H \times I_{T3}}$$

$$R_{T2} - R_{T3} = \frac{V_{D2}}{I_{T2}} - \frac{V_{D3}}{I_{T3}}$$

In the diode example illustrated in FIGS. **10-11**, a forward bias voltage for the diode may be different in the second and third measurements (V_{D2} , V_{D3}), for example due to different applied voltages. Therefore, rather than assuming that forward bias voltages are the same at different diode excitation levels (V_{D2} , V_{D3}) it can be assumed that:

$$V_{D3} = K \times V_{D2}$$

Where K is the increase in diode voltage caused by a higher diode excitation, and I_S is the diode's reverse bias saturation current, then a diode equation can be used to determine the following relationship between the diode voltages:

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$$K = \frac{V_{D3}}{V_{D2}} = \frac{\ln \frac{I_{D3}}{I_S}}{\ln \frac{I_{D2}}{I_S}} = \frac{\ln I_{D3} - \ln I_S}{\ln I_{D2} - \ln I_S}$$

If less accuracy is acceptable, K may be approximated as a constant, or even as equal to 1.

So

$$R_{T2} - R_{T3} = \frac{V_{D2}}{I_{T2}} - \frac{K \times V_{D2}}{I_{T3}}$$

$$I_{T2} \times I_{T3} \times (R_{T2} - R_{T3}) = I_{T3} \times V_{D2} - I_{T2} \times K \times V_{D2}$$

$$I_{T2} \times I_{T3} \times (R_{T2} - R_{T3}) = (I_{T3} - K \times I_{T2}) \times V_{D2}$$

$$V_{D2} = V_{D3} \div K = I_{T2} \times I_{T3} \times (R_{T2} - R_{T3}) \div (I_{T3} - K \times I_{T2})$$

This calculated value of V_{D2} can be used in the hose resistance calculation as follows:

$$R_H = R_{T1} - R_{T2} + \frac{V_{D2}}{I_{T2}}$$

Referring now to FIG. 13 overall, it is recognized that the two or more measurements and related calculations can be performed periodically, with the calculated hose resistance 206 (R_{Hose}) or other electrical characteristic of the hose tracked in the analysis unit 310. In such arrangements, changes in the calculated hose resistance (e.g., a lower or higher than expected resistance) may indicate impending failure of the hose, for example due to a breakdown in one or more layers 18-26 of the hose 16.

Detection of large contact resistance (R_C), and consisting also of wire resistance and monitoring unit connector and switch resistances, is important for detecting failure of the hose sensing circuit. R_C can be calculated from any of the following equations:

$$R_{T1} = R_C + R_H$$

$$R_{T2} = R_C + \frac{R_H \times R_{D2}}{R_H + R_{D2}}$$

$$R_{T3} = R_C + \frac{R_H \times R_{D3}}{R_H + R_{D3}}$$

The above specification, examples and data provide a complete description of the manufacture and use of the composition of the invention. Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

The invention claimed is:

1. A hose degradation monitoring system comprising:
 - a hose assembly including a hose having a first conductive layer and a second conductive layer;
 - a monitoring circuit in electrical communication with the first and second conductive layers, the monitoring circuit including a circuit element having a non-linear electrical property in response to changed voltage, the monitoring circuit mounted in a monitoring assembly

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including a circuit board electrically connected at contacts to the first conductive layer and the second conductive layer;

wherein the monitoring circuit includes a diagnostic unit configured to apply a plurality of different voltages across the circuit element, the plurality of different voltages including at least a first voltage, a second voltage, and a third voltage, and

wherein the monitoring circuit is further configured to calculate an electrical characteristic of the hose assembly based at least in part on electrical characteristics of the hose assembly in response to the plurality of different voltages while accounting for a resistance of the contacts determined based at least in part on a response to the non-linear electrical property of the circuit element.

2. The hose fault detection system of claim 1, wherein the diagnostic unit is located remotely from the hose assembly.

3. The hose fault detection system of claim 1, further comprising a monitoring assembly including a housing and a circuit board, the circuit board positioned in a channel of the housing and including electrical contacts oriented toward the hose assembly, the electrical contacts electrically connecting the monitoring circuit to the first and second conductive layers.

4. The hose fault detection system of claim 1, wherein the circuit element includes a diode connected across the first and second conductive layers.

5. The hose fault detection system of claim 4, wherein the diode has a resistance that changes non-linearly as a function of voltage applied across the diode.

6. The hose fault detection system of claim 1, wherein the monitoring circuit is at least partially incorporated in a monitoring assembly mounted to the hose assembly.

7. A method of monitoring degradation of a hose assembly, the method comprising:

applying a first voltage across a circuit element connected between first and second conductive layers of a hose assembly;

while applying the first voltage, detecting a first electrical characteristic of the circuit element;

applying a second voltage across the circuit element, the second voltage different from the first voltage;

while applying the second voltage, detecting a second electrical characteristic of the circuit element;

applying a third voltage across the circuit element, the third voltage different from the first and second voltages;

while applying the third voltage, detecting a third electrical characteristic of the circuit element; and

calculating an electrical characteristic of the hose assembly based at least in part on the first and second electrical characteristics.

8. The method of claim 7, wherein calculating the electrical characteristic of the hose assembly is further based on the third electrical characteristic.

9. The method of claim 7, wherein the second voltage is a voltage opposite that of the first voltage.

10. The method of claim 7, wherein calculating an electrical characteristic of the hose assembly comprises calculating a resistance of the hose assembly.

11. The method of claim 10, wherein the resistance of the hose assembly is calculated using the equation:

$$R_H = R_{T1} - R_{T2} + \frac{V_{D2}}{I_{T2}}$$

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wherein R_H is the resistance of the hose assembly, R_{T1} is a combination of the resistance of the hose assembly and a contact resistance, R_{T2} is a combination of the contact resistance with a parallel resistance of the hose assembly and a diode resistance, V_{D2} is the second voltage, and I_{T2} is a total current. 5

12. The method of claim 7, further comprising calculating an electrical characteristic of the circuit, wherein calculation of an abnormal electrical characteristic of the circuit represents a circuit fault occurring in the monitoring assembly. 10

13. The method of claim 12, wherein the calculating the electrical characteristic of the circuit comprises calculating a large contact resistance.

14. A hose degradation monitoring system comprising:
 a hose assembly including a hose having a first conductive layer and a second conductive layer; 15
 a monitoring circuit including a diode electrically connected between the first conductive layer and the second conductive layer, wherein the diode has a resistance that changes non-linearly as a function of voltage applied across the diode; and

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a monitoring assembly including a housing and a circuit board, the circuit board positioned in a channel of the housing and including electrical contacts oriented toward the hose assembly, the electrical contacts electrically connecting the monitoring circuit to the first and second conductive layers;

wherein the monitoring circuit includes a diagnostic unit configured to apply a plurality of different voltages across the diode, the plurality of different voltages including at least a first voltage, a second voltage, and a third voltage, and

wherein the monitoring circuit further configured to calculate an electrical characteristic of the hose assembly based at least in part on electrical characteristics of the hose assembly in response to the plurality of different voltages while accounting for a resistance of the contacts determined based at least in part on a response to the non-linear resistance of the diode.

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